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DESCRIPTION

THREE-DIMENSIONAL PHOTONIC STRUCTURE AND METHOD FOR MANUFACTURING THREE-DIMENSIONAL PHOTONIC STRUCTURE

Technical Field

[0001]

The present invention relates to a three-dimensional photonic structure and a method for manufacturing the three-dimensional photonic structure. In particular, the present invention relates to a method for manufacturing a three-dimensional photonic structure having a plurality of inorganic members disposed at specific positions in a resin and relates to a three-dimensional photonic structure produced by the method.

Background Art

[0002]

Photonic crystals have structures each having material bodies periodically disposed in a specific substance, each of the material bodies having a dielectric constant different from the dielectric constant of the specific substance, and the photonic crystals completely reflect electromagnetic waves having specific wavelengths due to mutual interference of electromagnetic waves. The frequencies of such electromagnetic waves completely reflected exhibit a specific range, which is called

"photonic band gap".

[0003]

When an electromagnetic wave enters a periodic dielectric structure, two kinds of standing waves are formed by Bragg diffraction. One standing wave oscillates in a region having a low dielectric constant, another standing wave oscillates in a region having a high dielectric constant. The former has an energy level higher than that of the latter. That is, waves having energy levels between energy levels of the two standing waves, which have different modes from each other, cannot enter in the crystal; therefore, a photonic band gap is formed.

[0004]

Since photonic band gaps, as described above, are formed by Bragg diffraction, it is necessary that lattice constants, which are repetition periods in periodic structures, correspond to wavelengths. An increase in the difference between dielectric constants increases the difference between vibrational energy levels in dielectric phases, thus increasing the photonic band gap. A higher dielectric constant reduces vibrational energy. As a result, the photonic band gap shifts to lower frequencies.

[0005]

Various photonic crystals have been developed. To completely reflect a three-dimensional electromagnetic wave,

it is necessary to form a photonic band gap in all directions. A photonic crystal that meets such a demand includes, for example, a diamond structure. However, since diamond structure is complicated, it is difficult to manufacture such a diamond structure. Nowadays, a process for manufacturing a photonic crystal by stereolithography is drawing attention.

[0006]

Examples of processes for manufacturing photonic crystals by stereolithography include the following approaches.

[0007]

First, for example, Japanese Unexamined Patent Application Publication No. 2000-341031 discloses a process for manufacturing a photonic crystal as follows: Two-dimensional basic structures each having a plurality of rods are formed and successively stacked to produce a photonic crystal by stereolithography with a composite material composed of a photocurable resin containing a powdered dielectric ceramic.

[0008]

Second, for example, Japanese Translation Patent Publication No. 2001-502256 discloses a process in which a three-dimensional component, which is composed of a photocurable resin, having voids formed at predetermined

positions is manufactured and then a composite material composed of a resin into which dielectric ceramic powders are dispersed is charged into the voids.

[0009]

For example, Japanese Unexamined Patent Application Publication No. 2001-237616 discloses a process, where stereolithography is not applied, in which a coating containing a powdered low-dielectric ceramic is printed in a dot pattern on a green sheet containing a powdered high-dielectric ceramic and then the resulting green sheets are stacked, followed by sintering.

[0010]

However, the above-described processes have problems to be solved.

[0011]

It is difficult to manufacture a photonic crystal that contains a low-loss dielectric having high-dielectric constant by these processes disclosed in Japanese Unexamined Patent Application Publication No. 2000-341031 and Japanese Translation Patent Publication No. 2001-502256. Because, in these processes disclosed in these Patent Publications, a composite material composed of a resin into which a powdered dielectric ceramic is dispersed is used as a dielectric.

[0012]

A process disclosed in Japanese Unexamined Patent

Application Publication No. 2000-341031 applies the difference between the dielectric constant of a composite material composed of a resin mixed with a powdered dielectric ceramic and the dielectric constant of air that is present between rods composed of the composite material. In this case, since the dielectric constant of the composite material is determined by the mixing ratio of the resin and the powdered dielectric ceramic, the above-described difference between these dielectric constants is only determined by the dielectric constant of the composite material. As a result, the range of the resulting photonic band gap is limited.

[0013]

In each process disclosed in Japanese Unexamined Patent Application Publication No. 2000-341031 and Japanese Translation Patent Publication No. 2001-502256, it is necessary to supply a liquid photocurable resin so as to form a layer having a predetermined thickness on a platform by gradually lowering the platform. Accordingly, the use of a liquid photocurable resin having too high viscosity barely forms any shape. Hence, in a process, particularly disclosed in Japanese Translation Patent Publication No. 2001-502256, when a powdered dielectric ceramic is mixed with a liquid photocurable resin, the content of the powdered dielectric ceramic is limited, i.e., about 60% at

the highest. Even when the content of the powdered dielectric ceramic is about 60%, which is the upper limit, the dielectric constant of the composite material is 1/4 or less of that of the dielectric ceramic used. Therefore, high contrast photonic crystals are barely produced.

[0014]

On the other hand, in a process disclosed in Japanese Unexamined Patent Application Publication No. 2001-237616, since dots composed of a powdered low-dielectric ceramic are merely printed, these dots are hardly formed in the form of substantially three-dimensional shapes. Furthermore, these dots are hardly disposed at desired positions along the stacking direction because of the limitation caused by the thickness of the green sheet. In addition, since the green sheets and the dots are shrunk when sintering, it is difficult to design them so as to dispose the dots at a desired period in the sintered body and so as to form a desired photonic band gap.

[Patent Document 1] Japanese Unexamined Patent Application Publication No. 2000-341031.

[Patent Document 2] Japanese Translation Patent Publication No. 2001-502256.

[Patent Document 3] Japanese Unexamined Patent Application Publication No. 2001-237616.

Disclosure of Invention

[0015]

It is an object of the present invention to provide a method for manufacturing a three-dimensional photonic structure and a three-dimensional photonic structure manufactured by the method, the method being able to solve above-described problems.

[0016]

The present invention provides a method for manufacturing a three-dimensional photonic structure having a plurality of inorganic members composed of a inorganic material and a resin matrix, within which the plurality of inorganic members are disposed, composed of a photocurable resin material. To solve the above-described problems, the method includes the following aspects.

[0017]

The plurality of inorganic members and a photocurable resin material are prepared.

[0018]

A stereolithographic step of successively and repeatedly curing stacked layers composed of the photocurable resin material along the stacking direction to form a three-dimensional component such that cavities filled with the photocurable resin material are formed at positions to be occupied by the inorganic members in the three-dimensional component having a structure in which the

plurality of cured resin layers composed of the photo-cured resin material are stacked, is performed.

[0019]

An inserting substep of inserting the inorganic members into concave portions when the concave portions are formed before closing the cavities during the stereolithographic step is performed, each of the concave portions being at least part of the corresponding cavity and having an opening through which each of the inorganic members can pass, each gap between the surface of each of the concave portions and the corresponding inorganic member being filled with the photocurable resin material.

[0020]

The photocurable resin material in each of the gaps is thermally cured.

[0021]

The method for manufacturing a three-dimensional photonic structure according to the present invention further includes the steps of generating the three-dimensional data of the shape of the three-dimensional component in advance; generating slice data from the three-dimensional data, the slice data being generated by slicing the three-dimensional component in a direction perpendicular to the stacking direction of the three-dimensional component; and generating raster data for scanning laser

light from the slice data, wherein, in the stereolithographic step, the photocurable resin material is preferably cured repeatedly in the form of layers by scanning the laser light according to the raster data.

[0022]

The inorganic members each having a dielectric constant higher than that of the photo-cured resin material are preferably used. In this case, the inorganic members are preferably each a ceramic sinter.

[0023]

The photocurable resin material used may be capable of forming a plurality of pores within the photocurable resin.

[0024]

The present invention also relates to a three-dimensional photonic structure manufactured by the method described above.

[0025]

As described above, according to the present invention, a three-dimensional component having a structure, in which a plurality of cured resin layers composed of the photo-cured resin material are stacked, and having cavities containing the photocurable resin material is produced by a stereolithographic step. In addition, the inorganic members are inserted into concave portions when the concave portions are formed before closing the cavities during the

stereolithographic step, each of the concave portions being at least part of the corresponding cavity, the photocurable resin material remaining in the concave portions. Then, the photocurable resin material in the cavities is thermally cured. Consequently, the plurality of inorganic members can be disposed at desired periodic positions with precision.

[0026]

Furthermore, the inorganic members are prepared independently; hence, the dielectric constants, sizes, shapes, and the like of the inorganic members may be adjusted as desired before inserting them into the concave portions. These dielectric constants, sizes, shapes, and the like are maintained in the resulting three-dimensional photonic structure. In addition, the spaces between the plurality of inorganic members may be set as desired.

[0027]

Consequently, according to a three-dimensional photonic structure of the present invention, the effect of a photonic band gap corresponding to desired wavelengths can be achieved. A satisfactorily-wide photonic band gap can also be achieved. As a result, electromagnetic waves having specific wavelengths can be shielded with high contrast. For example, highly efficient electromagnetic-wave filters and electromagnetic barriers can be manufactured.

[0028]

The present invention includes the steps of generating the three-dimensional data of the shape of the three-dimensional component in advance; generating slice data from the three-dimensional data, the slice data being generated by slicing the three-dimensional component in a direction perpendicular to the stacking direction of the three-dimensional component; and generating raster data for scanning laser light from the slice data, wherein, in the stereolithographic step, the photocurable resin material is repeatedly cured in the form of layers by scanning the laser light according to the raster data. Therefore, the preparing step before the stereolithographic step and the stereolithographic step can progress efficiently.

[0029]

As described above, according to the present invention, since dielectric constants of the inorganic members can be adjusted as desired, inorganic members each having a dielectric constant higher than that of the photo-cured resin material can be easily used. As a result, a photonic crystal having a greater difference between dielectric constants can be manufactured. Therefore, the photonic band gap can be easily increased.

[0030]

The use of ceramic sintered bodies as the inorganic members described above does not cause a nonuniform

distribution of the dielectric constant within the inorganic members, thus easily manufacturing a three-dimensional photonic structure having a desired photonic band gap. In addition, such inorganic members are stable with respect to temperature and humidity.

[0031]

In the present invention, the use of a photocurable resin material capable of forming a plurality of pores within the photocurable resin material can reduce the dielectric constant of the resin matrix in the three-dimensional photonic structure compared with that of a photocurable resin material having no pores. Therefore, a greater difference of the dielectric constants between the resin matrix and the inorganic members can be achieved.

Brief Description of the Drawings

[0032]

[Fig. 1] Fig. 1 is a perspective view showing a three-dimensional photonic structure 1, in which the upper portion of the three-dimensional photonic structure 1 is cut away, according to an embodiment of the present invention.

[Fig. 2] Fig. 2 illustrates a step of generating slice data of a three-dimensional component 4 in order to manufacture the three-dimensional photonic structure 1 shown in Fig. 1.

[Fig. 3] Fig. 3 is a schematic front view of a

stereolithograph 6 used in a stereolithographic step of manufacturing the three-dimensional photonic structure 1.

[Fig. 4] Fig. 4 is a fragmentary cross-sectional view of the three-dimensional component 4 and illustrates states at some points in the stereolithographic step performed with the stereolithograph 6 shown in Fig. 3 in time sequence.

[Fig. 5] Fig. 5 is a graph showing the propagation properties of electromagnetic waves in the three-dimensional photonic structure 1 manufactured according to an embodiment of the present invention.

[Fig. 6] Fig. 6 is a schematic front view illustrating a three-dimensional photonic structure 21 according to another embodiment of the present invention.

Reference Numerals

[0033]

1, 21 three-dimensional photonic structure

2 inorganic member

3 resin matrix

4 three-dimensional component

5 plane perpendicular to stacking direction

6 stereolithograph

7 laser light source

8 laser light

9 position to be occupied by inorganic member

10 photocurable resin material

12 platform

14 liquid level

15 scanning mirror

17 cured resin layer

18 cavity

19 opening

20 concave portion

Best Mode for Carrying Out the Invention

[0034]

A three-dimensional photonic structure 1 according to an embodiment of the present invention will now be described with reference to Fig. 1. In Fig. 1, to show part of the inner structure of the three-dimensional photonic structure 1, the three-dimensional photonic structure 1 in which the upper portion of the three-dimensional photonic structure 1 is cut away is illustrated.

[0035]

The three-dimensional photonic structure 1 is provided with a plurality of inorganic members 2 composed of an inorganic material and a resin matrix 3 within which the plurality of inorganic members 2 are disposed, the resin matrix 3 being composed of a photocurable resin material.

[0036]

Each of the inorganic members 2 preferably has a dielectric constant higher than that of the resin matrix 3

and, for example, is a ceramic sinter. Examples of the high-dielectric ceramics constituting the inorganic members 2 include $BaTiO_3$, $PbTiO_3$, $NaVO_3$, $(Ba,Sr)TiO_3$, $KNbO_3$, $LiTaO_3$, $(Ba,Pb)ZrO_3$, $Pb(Mg,W)ZrO_3$, $Pb(Mg,Nb)ZrO_3$, $Pb(Zr,Ti)O_3$, $CaTiO_3$, and TiO_2. Furthermore, the materials constituting the inorganic members 2 are not limited to the above-described high-dielectric ceramics, but include, for example, crystals of high-dielectric materials (single crystals may be used) and composites composed of high-dielectric materials.

[0037]

As described above, the inorganic members 2 composed of high-dielectric material can easily achieve a dielectric constant higher than that of a composite material composed of a resin containing a powdered dielectric ceramic and can achieve a uniform dielectric constant within the inorganic members. Alternatively, the inorganic members 2 composed of ceramic sintered bodies are stable with respect to, for example, temperature and humidity.

[0038]

In this embodiment, the inorganic members 2 have spherical shapes. However, the shapes of the inorganic members 2 are not limited to spherical shapes, but may include, for example, prisms, polyhedrons, rhombohedrons, cones, and cylinders.

[0039]

On the other hand, examples of photocurable resin materials constituting the resin matrix 3 include epoxy photocurable resins and acrylate photocurable resins. To adjust the dielectric constants of these photo-cured resins, for example, dielectric ceramic particles may be mixed and dispersed into such resin materials.

[0040]

In the three-dimensional photonic structure 1 shown in Fig. 1, only the inorganic members 2 are partially illustrated. In fact, a plurality of inorganic members 2 are disposed so as to form, for example, a diamond structure.

[0041]

To manufacture the three-dimensional photonic structure 1 shown in Fig. 1, the following steps are performed.

[0042]

A three-dimensional component corresponding to the resin matrix 3 of the three-dimensional photonic structure 1 to be manufactured is designed with a computer-aided design (CAD) program and then converted into stereolithographic (STL) data, which is three-dimensional data approximated with a triangular mesh.

[0043]

The STL data is loaded into a computer. As shown in Fig. 2, slice data is generated from this STL data, the slice data being generated by slicing the three-dimensional

component 4 along a plane 5 perpendicular to the stacking direction of the three-dimensional component 4.

[0044]

Next, raster data is generated from the slice data, the raster data functioning as scanning data for controlling the scan mode of laser light 8, such as ultraviolet laser light, emitted from a laser light source 7 equipped with the stereolithograph 6 shown in Fig. 3.

[0045]

Consequently, as shown in Fig. 2, positions 9 to be three-dimensionally occupied by the inorganic members 2 in the three-dimensional component 4 are determined.

[0046]

The plurality of inorganic members 2 and the photocurable resin material, both of which constitute the three-dimensional photonic structure 1, are prepared and then a stereolithographic step is performed with the stereolithograph 6 shown in Fig. 3.

[0047]

Fig. 3 is a schematic front view of the stereolithograph 6.

[0048]

The stereolithograph 6 is provided with a bath 11 containing a photocurable resin material 10. A platform 12 for manufacturing the three-dimensional component 4 (see Fig.

4) on the platform 12 is disposed in the bath 11. As indicated by an arrow 13, the platform 12 is driven so as to be gradually lowered to predetermined heights.

[0049]

A scanning mirror 15, which reflects the laser light 8 emitted from the laser light source 7 toward a liquid level 14 of the photocurable resin material 10, is disposed above the platform 12. The scanning mirror 15 is disposed such that an angle of reflection can be changed according to the raster data. The laser light 8 scans along the liquid level 14 with the mirror in directions indicated by a double headed arrow 16. The portion of the photocurable resin material 10 scanned by the laser light 8 is cured.

[0050]

As shown in Fig. 3, the platform 12 is disposed so as to supply the liquid photocurable resin material 10 between the platform 12 and the liquid level 14 to form a layer having a predetermined thickness, for example, 100 μm. The liquid level 14 is adjusted by a squeegee and then the excess of the photocurable resin material 10 is returned to the bath 11. In this state, the laser light 8 scans across the photocurable resin material 10 according to the above-described raster data, so that the photocurable resin material 10 is cured into a cured resin layer 17 at the portion irradiated with the laser light 8.

[0051]

Next, the platform 12 is moved to the direction indicated by the arrow 13 so as to resupply the photocurable resin material 10 between the resulting cured resin layer 17 and the liquid level 14 to form a layer having a predetermined thickness. Then, the laser light 8 is rescaned according to the raster data. In this way, another cured resin layer 17 composed of the photo-cured resin material 10 is formed.

[0052]

As described above, the formation of the cured resin layer 17 irradiated with the laser light 8 and the downward transfer of the platform 12 are repeated. In this way, the three-dimensional structure 4 having a structure in which a plurality of cured resin layers 17 composed of the photo-cured resin material 10 are stacked is produced by successively curing stacked layers composed of the photocurable resin material 10 from one end along the stacking direction.

[0053]

When the three-dimensional component 4 is manufactured by the above-described stereolithographic step, as shown in Fig. 4, cavities 18 are formed at positions to be occupied by the inorganic members 2, the cavity 18 being filled with the photocurable resin material 10. Fig. 4 illustrates

states at some points in the stereolithographic step; in particular, Fig. 4 (1) illustrates a state before covering the cavity 18.

[0054]

As shown in Fig. 4 (1), when concave portions 20, each of which is to be included in at least part of the corresponding cavity 18 and has an opening 19 through which each of the inorganic members 2 can pass, are completed before covering the cavities 18, as shown in Fig. 4 (2), the inorganic members 2 are inserted into the respective concave portions 20. At this time, the photocurable resin material 10 remains between the surface of each of the concave portions 20 and the corresponding inorganic material body 2.

[0055]

In the step of inserting the inorganic members 2 into the concave portions 20 described above, the photocurable resin material 10 in each concave portion 20 can overflow from the opening 19. When such an overflow of the photocurable resin material 10 is undesired, the overflowed photocurable resin material 10 may be removed with, for example, a squeegee.

[0056]

After inserting the inorganic members 2 as described above, the stereolithographic step is subsequently performed. As shown in Fig. 4 (3), the concave portions 20 are covered

with the respective cured resin layers 17 to form cavities 18.

[0057]

In this embodiment with reference to Fig. 4, each of the inorganic members 2 is inserted when each of the concave portions 20 having a size capable of containing the entire inorganic member 2 is formed. Alternatively, each of the inorganic members 2 may be inserted into the corresponding concave portion 20 when each of the concave portions 20 having a size capable of containing, for example, only the lower half of the inorganic member 2 is formed.

[0058]

When the photocurable resin material 10 has a low viscosity, the inorganic members 2 may be disposed at predetermined positions in the cured resin layers 17 before the substantial formation of the concave portions 20, and then the cavities 19 may be formed.

[0059]

Consequently, a three-dimensional component 4 having a structure in which the plurality of the cured resin layers 17 are stacked is manufactured; the three-dimensional component 4 also includes a plurality of cavities 18 disposed at predetermined positions, the inorganic members 2 are positioned in the respective cavities 18, and the photocurable resin material 10 is charged in each of the

cavities 18.

[0060]

Next, a step of thermally curing the photocurable resin material 10 in the cavities 18 is performed. In this thermally curing step, heat treatment is performed, for example, at 60°C for 4 hours. Each of the inorganic members 2 is brought into intimate contact with the photocurable resin material 10 by this thermally curing step. When the photocurable resin material 10 is not cured and not in intimate contact with each inorganic member 2, low-dielectric portions are formed around the respective inorganic members 2. As a result, a photonic band gap sometimes cannot be formed as desired.

[0061]

A three-dimensional structure 1 that has a lattice constant of 12 mm and inorganic members 2, each having a spherical shape and having a diameter of 3 mm, composed of stabilized zirconia was manufactured as an example of the present invention by the above-described manufacturing method. This three-dimensional structure 1 was placed in a waveguide, and then its electromagnetic propagation properties were measured. As a result, as shown in Fig. 5, a wide photonic band gap was observed.

[0062]

Fig. 6 is a schematic front view illustrating a three-

dimensional photonic structure 21 according to another embodiment of the present invention.

[0063]

In Fig. 6, the hatched portions represent regions 22 containing inorganic members disposed at a constant period, as shown in Fig. 1, while the other portion represents a defect region 23 containing no inorganic members and thus no lattice. The defect region 23 may be formed entirely or partially along a layer.

[0064]

The method according to the present invention can easily manufacture even the three-dimensional photonic structure 21 containing the defect region 23, as shown in Fig. 6.

[0065]

As described above, the present invention is described with reference to these embodiments. The present invention can be modified within the scope of the present invention.

[0066]

For example, a three-dimensional structure 1 having a plurality of pores within a resin matrix 3 may be manufactured with a photocurable resin material 10 containing hollow microcapsules. In this case, the resin matrix 3 having a lower dielectric constant can be achieved.

[0067]

In the above-described embodiments, each of the inorganic members 2 has a dielectric constant higher than that of the resin matrix 3. On the contrary, for example, by the use of a resin matrix 3 containing high-dielectric ceramic particles, each of the inorganic members 2 may have a dielectric constant lower than that of the resin matrix 3.

[0068]

In this way, the combination of the dielectric constants of the inorganic material portion and the resin matrix can adjust the photonic band gap as desired.

[0069]

In the above-described embodiments, a plurality of inorganic members 2, which have the same size and are composed of the same material as each other, are disposed in the three-dimensional structure 1. Alternatively, at least two kinds of inorganic members, which have different sizes and/or are composed of different materials from each other, may be disposed. That is, the photonic band gap is generated when inorganic members having the same size and the same material are merely disposed at a constant period. Therefore, even when a plurality of kinds of inorganic members are disposed in one three-dimensional photonic structure, among these inorganic members, inorganic members having the same size and being composed of the same material only need to be disposed at a constant period.

[0070]

In the above-described embodiments, each of the cavities has a shape along the shape of the respective inorganic members. For example, when inorganic members, each having a spherical shape, are inserted, each of the cavities may have a cylinder shape. That is, each of the cavities does not always have a shape along the shape of the respective inorganic member, provided that positioning can be surely achieved.

Industrial Applicability

A three-dimensional photonic structure according to the present invention can be used to manufacture, for example, highly efficient electromagnetic-wave filters and electromagnetic-wave barriers, which are required for shielding electromagnetic waves having specific wavelengths with high contrast.